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MODAL AND STRUCTURAL ANALYSIS OF POLYMER COMPOSITE VAWT SAVONIUS BLADE USING ANSYS WORKBENCH

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ABSTRACT

Any wind turbines efficiency mainly depends on the material of the wind turbine, shape of the turbine blade, speed of the wind and blade angle. Here material plays an important role in design of wind turbine blade. Wind turbine blades are mostly made of more density materials such as steel and aluminum. This is main cause for huge weight and it has less fatigue strength and more corrosion rate. The high density materials can be replaced by composite materials such as GFRP to reduce the weight of the turbine, to improve fatigue strength and corrosion resistance and to make them more efficient. Here Glass Fiber Reinforced Polymer (GFRP) material was used to model wind turbine of one meter height and one meter diameter with four different arc radiuses.

Modeling software Solid Works is used to model wind blade of four different shapes with GFRP material and static structural analysis and modal analysis of the GFRP wind blade is done by using Ansys Workbench analysis Software.

KEYWORDS: GFRP, Structural Analysis, Modal Analysis & ANSYS Workbench

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Original Article

INTRODUCTION

Savonius vertical axis wind turbine is one category of wind turbine which converts the wind force into electric power. This turbine consists of minimum two blades to more number of blades vertically mounted on a rotating shaft. The cost of this turbine is low and also it is reliable. But the efficiency of the turbine is poor when compared with horizontal axis wind turbine due to drag force. This turbine does not need any starting and pointing mechanism. Sigurd Johannes Savonius invented this VAWT wind turbine blade in the year 1922. It was not widely used for many years due to poor efficiency. Now it becomes more popular due to increase in the urbanized areas and need of green energy. The Savonius blade can satisfy these needs to produce green electrical power.

DESIGN CALCULATION

The wind power is directly proportional to density of air, swept area and the wind speed. The various relationships between the variables are provided in the following equation.

$$P_w = \tfrac{1}{2} \rho A V^3$$

Where P_w = Wind Power (W)

ρ = Density of air = 1.23 kg/m^3

A = Swept area (m^2)

V = Speed of wind (m/s)

The angular velocity

ω = (λ x V) / R

λ = Tip speed ratio.

λ is around unity for a savonius rotor.

R = Rotor Radius

A rotating body output is obtained from the multiplication of torque and angular speed.

P = M x ω

P = Output (N-m/s)

M = Torque (N-m)

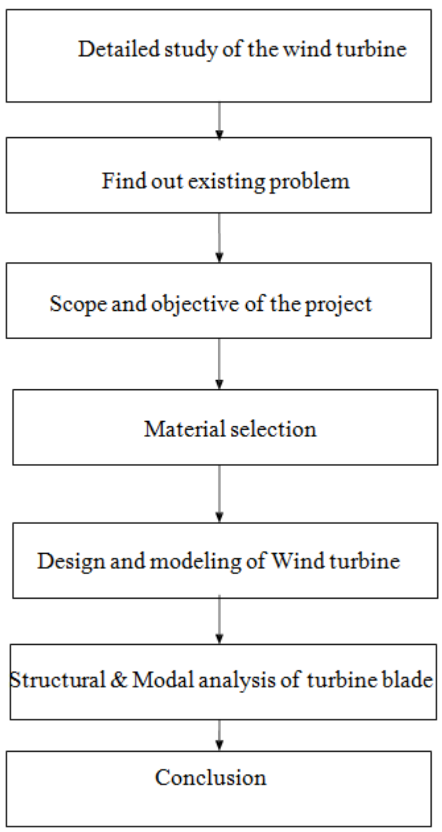
ω = Angular speed / second = 2 π n / 60

n = Rotational speed (rpm) = (60 ω) / 2π

M = 60 P / 2 π n The maximum power a rotor according to Betz's law is

P_{max} = 16/27 * 1/2 *ρ * d * h * v^3

METHODOLOGY



The methodology used in this research work is given in the above flow chart. After detailed study of the savonius VAWT, it is found that material of a blade is the existing problem. Here polymer material is chosen to design the wind blade which is low density when compared to steel. The ultimate aim of the project is to reduce the weight and cost of the VAWT blade. Here four different shapes of the turbine blade using Glass Fiber Reinforced Polymer material are designed with same dimension of one meter height and one meter diameter by changing arc radius. Modeling software solid works is used to design the wind blades. This design is exported to Ansys Workbench analysis software for doing structural and modal analysis to find out stress, strain and deformation at various loads and natural frequencies at six modes for all the four shapes of the blades. Finally the results are compared and optimized design of the wind blade is selected based on the analysis result.

Table 1: Torque and Power of the wind Turbine at different wind Speeds

Sl. No	Speed of Wind (m/s)	Angular Speed (rad/sec)	Rotational Speed (rpm)	P_{max} (Watts)	Torque (Nm)	Forcing Frequency of Rotor = (rpm/60) (Hz)
1	5	10	96	45.36	4.54	1.59
2	6	12	115	78.38	6.53	1.91
3	7	14	134	124.46	8.89	2.23
4	8	16	153	185.78	11.61	2.55
5	9	18	172	264.52	14.70	2.87
6	10	20	191	362.85	18.14	3.18
7	11	22	210	482.95	21.95	3.50
8	12	24	229	627.00	26.13	3.82
9	13	26	248	797.18	30.66	4.14
10	14	28	267	995.66	35.56	4.46
11	15	30	287	1224.62	40.82	4.78

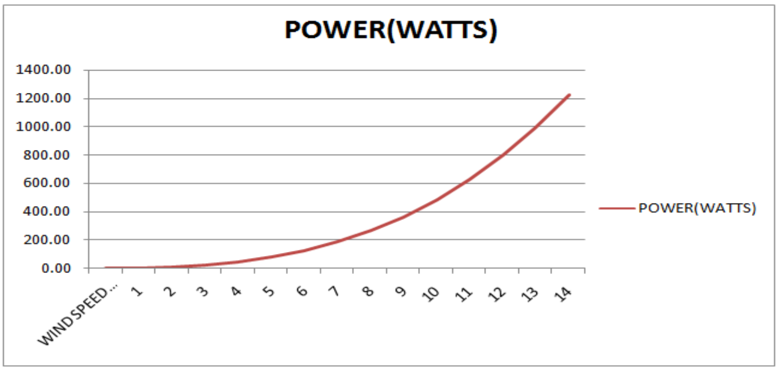


Figure 1: Speed of Wind Vs Power of Wind.

Design of Savonius Blade with Four Different Shapes

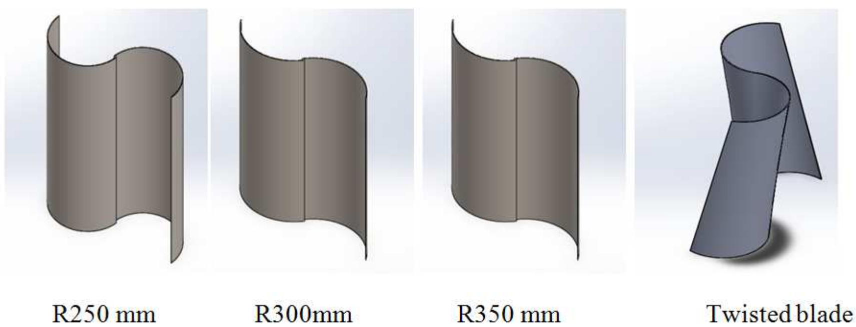


Figure 2: Four different Shapes of Wind Blades.

Dimension: Height x Rotor Diameter x Thickness = 1000 x 1000 x 3 mm

Each blade has different arc radius with same chord length of 500 mm.

Structural Analysis of Savonius Wind Blade

Here four different shapes of GFRP material wind blades are analyzed by applying loads of 500N, 1000N, 1500N and 2000N. Finally the results are compared for four different shapes.

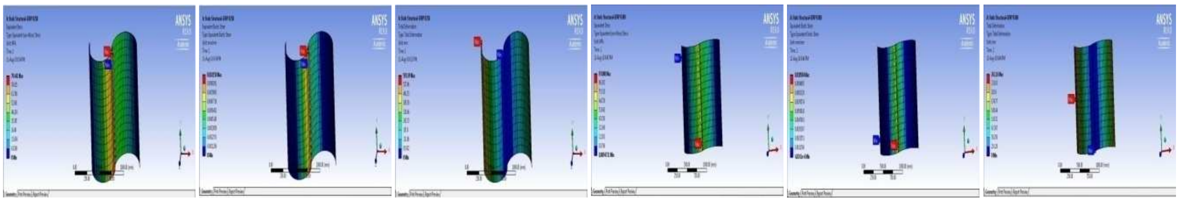


Figure 3: Stress, Strain and Deformation of R250 and R300 blade in 500N.

Figure 3 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius 250 mm and 300 mm at 500 N loads. The max. stress, strain and deformation for R250 mm blade are 79.4 MPa, 0.0102 and 593.3 mm respectively. For R300 mm, the maximum stress, strain and total deformation are 97.1 MPa, 0.0106 and 262.1 mm respectively.

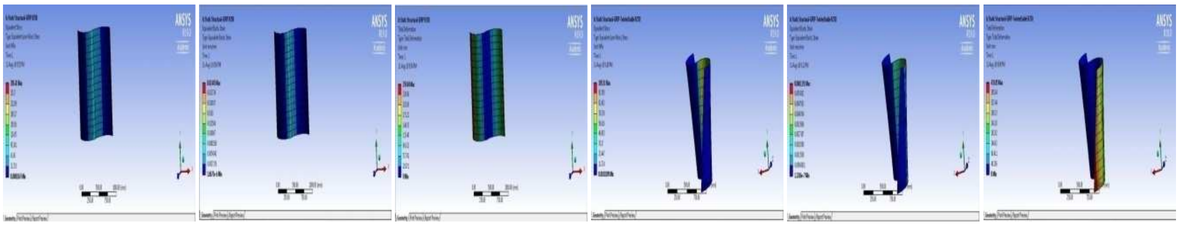


Figure 4: Stress, Strain and Deformation for R350 and Twisted with R250 in 500N.

Figure 4 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius 350 and twisted with R250 at 500 N loads. The maximum stress, strain and deformation for R350 are 285.4 MPa, 0.0245 and 259.8 mm respectively. For twisted blade, the maximum stress, strain and total deformation are 105.5 MPa, 0.0061 and 433.8 mm respectively.

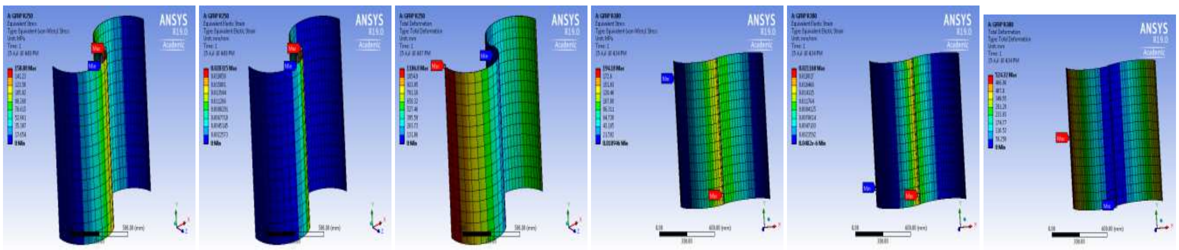


Figure 5: Stress, Strain and Deformation for R250 and R300 in 1000N.

Figure 5 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius 250 mm and 300 mm at 1000 N loads. The maximum stress, strain and deformation for R250 blade are 158.88 MPa, 0.020315 and 1186.8 mm respectively. For R300 mm, the maximum stress, strain and total deformation are 194.18 MPa, 0.02116 and 524.32 mm respectively.

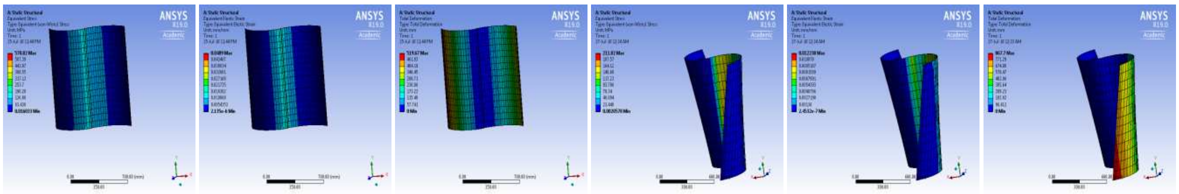


Figure 6: Stress, Strain and Deformation for R350 & Twisted with R250 in 1000N.

Figure 6 shows stress, strain and deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius R 350 and twisted with R250 at 1000 N. The maximum stress, strain and deformation for R350 are 570.82 MPa, 0.0489 and 519.67 mm respectively. For twisted blade, the maximum stress, strain and total deformation are 211.02 MPa, 0.012238 and 867.7 mm respectively.

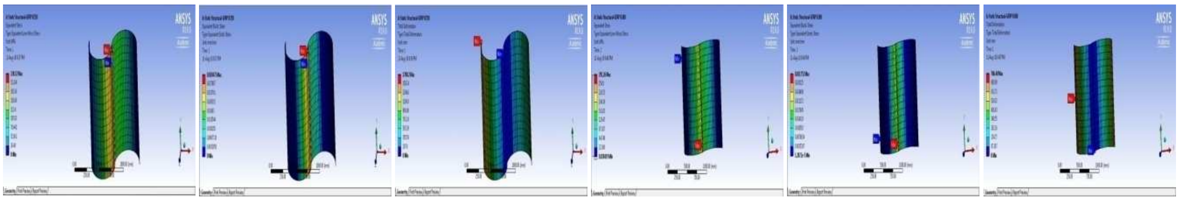


Figure 7: Stress, Strain and Deformation for R250 and R300 in 1500N.

Figure 7 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius 250 mm and 300 mm at 1500 N loads. The maximum stress, strain and deformation for R250 blade are 238.32 MPa, 0.0305 and 1780.2 mm respectively. For R300 mm, the maximum stress, strain and total deformation are 291.26 MPa, 0.0317 and 786.48 mm respectively.

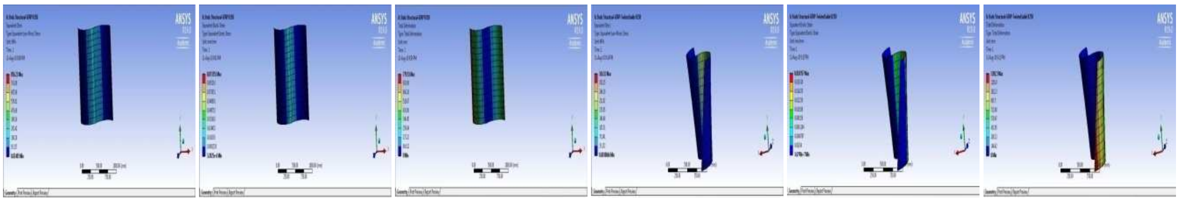


Figure 8: Stress, Strain and for R350 & Twisted with R250 in 1500N.

Figure 8 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius R350 and twisted with R250 at 1500 N. The maximum stress, strain and deformation for R350 blade are 856.22 MPa, 0.0734 and 779.51 mm respectively. For twisted blade, the maximum stress, strain and total deformation are 316.5 MPa, 0.0183 and 1301.5 mm respectively.

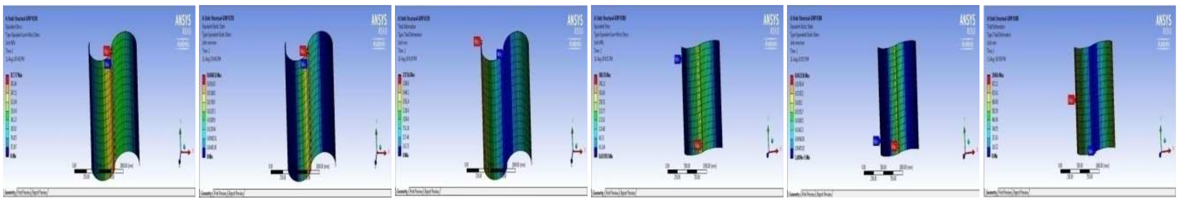


Figure 9: Stress, Strain and Deformation for R250 and R300 in 2000N.

Figure 9 shows stress, strain and total deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius 250 mm and 300 mm at 2000 N loads. The max. stress, strain and deformation for R250 blade are 317.77 MPa, 0.0406 and 2373.6 mm respectively. For R300 mm, the maximum stress, strain and total deformation are 388.35 MPa, 0.0423 and 1048.6 mm respectively.

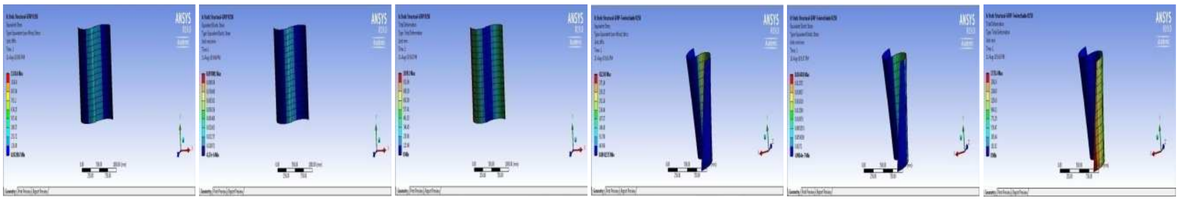


Figure 10: Stress, Strain and Deformation for R350 & Twisted with R250 in 2000N.

Figure 10 shows stress, strain and deformation of wind blade made of Glass Fiber Reinforced polymer with arc radius R 350 and twisted with R250 at 2000 N. The maximum stress, strain and deformation for R350 blade are 1141.6 MPa, 0.0978 and 1039.3 mm respectively. For twisted blade, the maximum stress, strain and total deformation are 422.03MPa, 0.0244 and 1735.4 mm respectively.

Modal Analysis of Savonius Wind Turbine Blade

Here all the different shapes of GFRP material wind blades are analyzed and the results are tabulated for comparison.

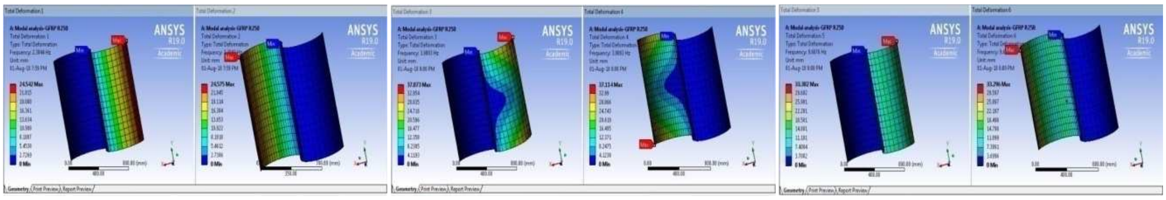


Figure 11: Natural Frequency and Total Deformation for R250 mm.

From Figure 11, natural frequency of wind blade made of Glass Fiber Reinforced Polymer with arc radius 250 mm at mode 1,2,3,4,5 and 6 are 2.384 Hz, 2.3943 Hz, 3.9803 Hz, 3.9893Hz, 9.60676 Hz and 9.6309 Hz respectively and total deformations are 24.542 mm, 24.575 mm, 37.073 mm, 37.114 mm, 33.302 mm and 33.296 mm respectively.

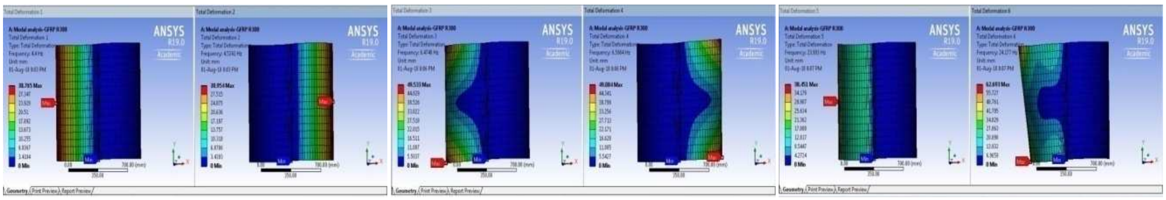


Figure 12: Natural Frequency and Total Deformation for R300 mm.

From Figure 12, natural frequency of wind blade made of Glass Fiber Reinforced Polymer with arc radius 300 mm at mode 1,2,3,4,5 and 6 are 4.4 Hz, 4.5 Hz, 6.47 Hz, 6.59 Hz, 23.99 Hz and 24.17 Hz respectively and total deformations are 30.76 mm, 30.95 mm, 49.53 mm, 49.88 mm, 39.45 mm and 62.69 mm respectively.

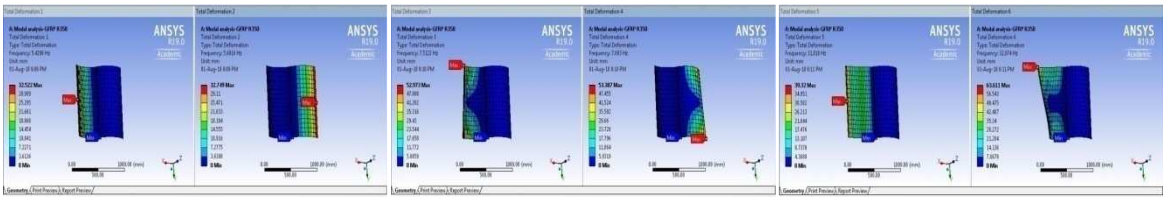


Figure 13: Natural Frequency and Total Deformation for R350 mm.

From Figure 13, natural frequency of wind blade made of Glass Fiber Reinforced Polymer with arc radius 350 mm at mode 1,2,3,4,5 and 6 are 5.43 Hz, 5.6 Hz, 7.5 Hz, 7.68 Hz, 31.81 Hz and 32.07 Hz respectively and total deformations are 32.52 mm, 32.75 mm, 52.97 mm, 53.38 mm, 39.32 mm and 63.61 mm respectively.

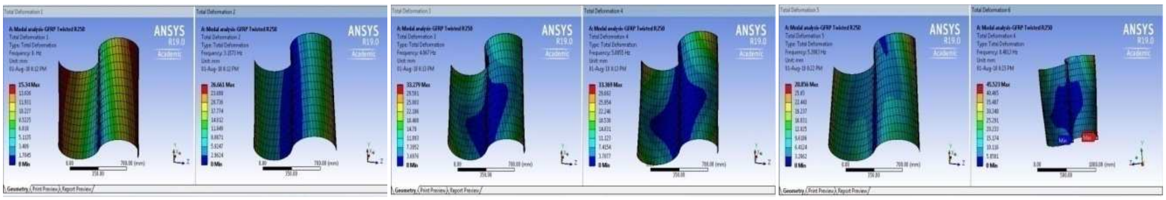


Figure 14: Natural Frequency and Deformation for Twisted Blade.

From Figure 14, natural frequency of wind blade made of Glass Fiber Reinforced Polymer with twisted arc radius 250 mm at mode 1,2,3,4,5 and 6 are 0.0013 Hz, 3.25 Hz, 4.06 Hz, 5.01 Hz, 5.39 Hz and 8.40 Hz respectively and total deformations are 15.34 mm, 26.66 mm, 33.28 mm, 33.37 mm, 28.86 mm and 45.52 mm respectively.

RESULTS AND DISCUSSIONS

Table 2: Load and Stress (MPA)

LOAD(N)	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	79.441	97.088	285.41	105.51
1000	158.88	194.18	570.82	211.02
1500	238.32	291.26	856.22	316.52
2000	317.77	388.35	1141.6	422.03

Table 2 shows Stress of wind blades at different loads for all four different shapes of the wind blades.

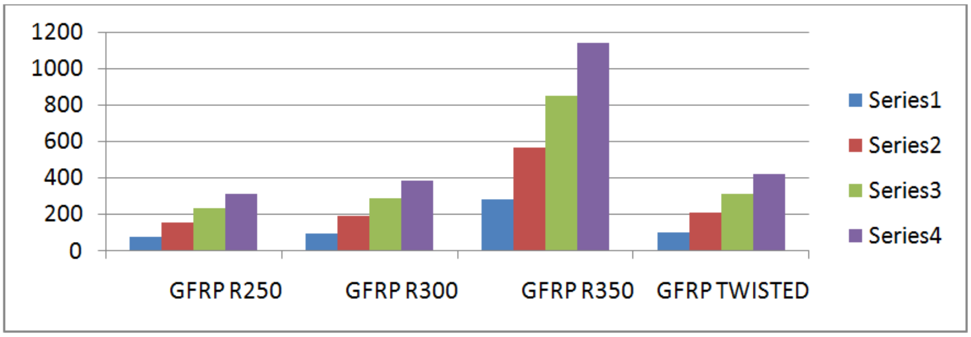


Figure 15: Load Vs Stress.

Figure 15 shows the Load Vs Stress chart of wind blades at different loads for all four different shapes of the wind blades.

Table 3: Load and Strain

LOAD (N)	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	0.010158	0.010584	0.02445	0.0061191
1000	0.020315	0.021168	0.0489	0.012238
1500	0.030473	0.031752	0.073351	0.018357
2000	0.040631	0.042336	0.097801	0.024476

Table 3 shows Strain of wind blades at different loads for all four different shapes of the wind blades.

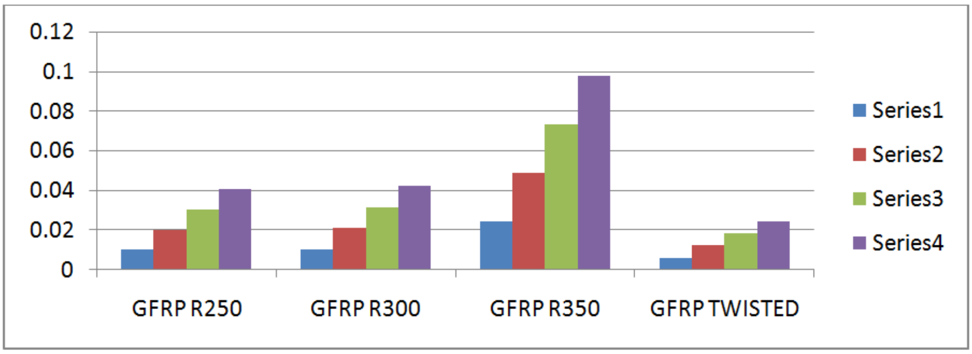


Figure 16: Load Vs Strain.

Figure 16 shows the Load Vs Strain chart of wind blades at different loads for all different shapes of the savonius wind blades.

Table 4: Load (N) Vs Deformation (mm)

LOAD(N)	GFRP R250	GFRP R300	GFRP R350	GFRP TWISTED
500	593.39	262.16	259.84	433.85
1000	1186.8	524.32	519.67	867.7
1500	1780.2	786.48	779.51	1301.5
2000	2373.6	1048.6	1039.3	1735.4

Table 4 shows Deformation of wind blades at different loads for all four different shapes of the wind blades.

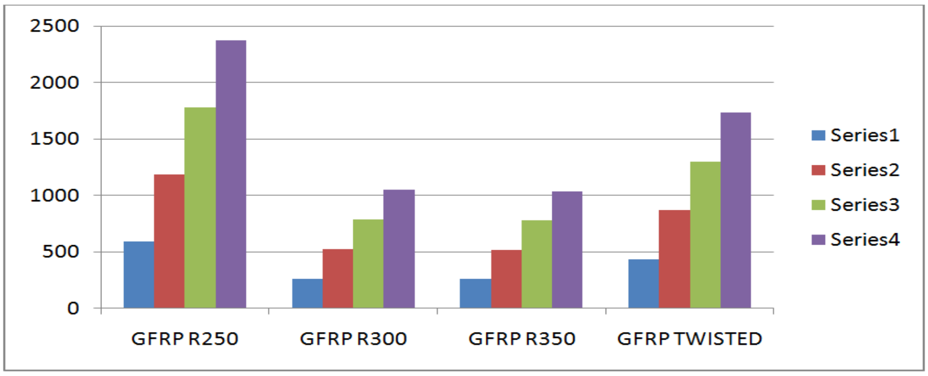


Figure 17: Load Vs Deformation.

Figure 17 shows the Load Vs Deformation chart of wind blades at different loads for all different shapes of the VAWT blade.

Table 5: Natural Frequency (Hz) and Deformation (mm) of Wind Blade

MODE	GFRP R250		GFRP R300		GFRP R350		GFRP TWISTED BLADE	
	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR	FREQ.	DEFOR
1	2.3844	24.542	4.4	30.765	5.4298	32.522	0.001	15.34
2	2.3943	24.575	4.5241	30.954	5.6016	32.749	3.1573	26.661
3	3.9803	37.073	6.4748	49.533	7.5122	52.973	4.067	33.279
4	3.9893	37.114	6.5964	49.884	7.683	53.387	5.0055	33.369
5	9.6076	33.302	23.993	38.451	31.818	39.32	5.3983	28.856
6	9.6309	33.296	24.177	62.693	32.074	63.611	8.4013	45.523

Natural frequency and deformation of wind blades at six modes for all shapes of the wind blades are shown in table 5.

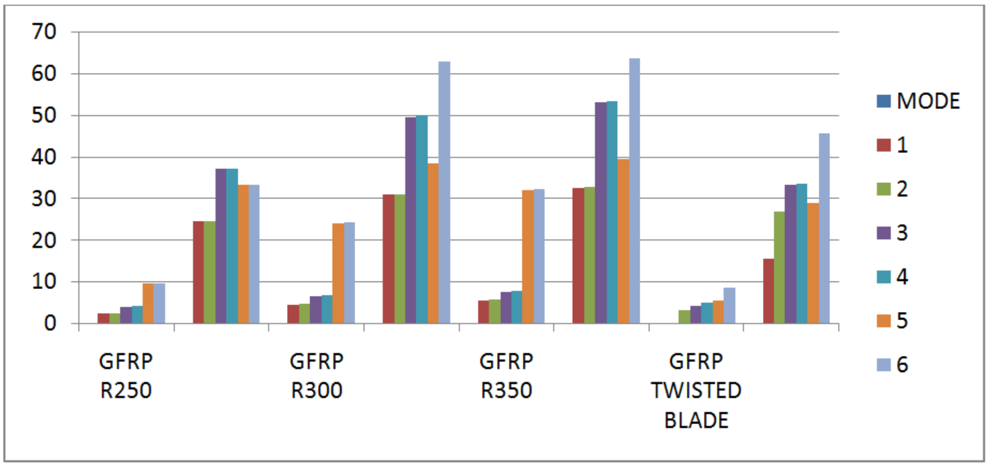


Figure 18: Natural Frequency (Hz) and Total Deformation (mm) at Different Mode Shapes.

Natural frequency and total deformation of wind blades at 6 modes for all different shapes of the wind blades are shown in figure 18.

Natural frequency is nothing but the frequency of the structure which tends to vibrate while it is disturbed. Mode shape in modal analysis is specific pattern of vibration of any structure to a specific frequency. Due to various rotational speeds (RPM) of the rotor, we obtain various forcing frequency which has been tabulated.

Forcing Frequency (Hz) = Rotational Speed in Revolution/Second

The natural frequency and forcing frequency of the rotor should not be equal. When it is equal, the structure of rotor will resonate which cause the increased amplitude of vibration and it may lead to failure of structure.

The max. Stress of 1142MPa and max. Strain of 0.09 is realized in GFRP R350 mm blade at 2000N. In this analysis, the natural frequencies of GFRP R250 mm at mode 1, 2, 3 and 4 are same with forcing frequency of wind speed from 7m/s to 12m/s in Table 1. In GFRP R300 mm, the natural frequency at mode 1 and 2 are same with forcing frequency at speed from 13m/s to 15m/s. In twisted blade, the natural frequency at mode 2 and 3 are same with forcing frequency at wind speed ranging from 10m/s to 13m/s. Hence there is a possibility for resonance. So structure failure may occur in R250 mm, R300 mm and twisted blades. But natural frequency of GFRP R350 mm at all modes differs from forcing frequency. In this case natural frequency does not match with forcing frequency. So there is no possibility for failure of structure. So R350 mm blade may be chosen for fabrication of savonius wind turbine blades. Moreover it will be less weight and cost.

CONCLUSIONS

The results from structural analysis to evaluate Stress, Strain and total deformation are found good and result shows that Glass Fiber Reinforced Polymer material is better choice to fabricate wind turbine blades. Modal analysis result also shows that the failure of structure will not happen. After comparing the analysis result of all the different shapes of the savonius VAWT blade, it is found that GFRP R350 mm blade is better and suitable choice for manufacturing.

It is suitable for houses in urban areas to produce green electrical energy which can produce electric power of 362 Watts and 1225 Watts at the wind speed of 10 m/s and 15 m/s respectively. We can reduce the weight of the material by 1/4th of steel and manufacturing cost by 50%.

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